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FLEXIBLE AND SCALABLE ARCHITECTURE FOR DWDM NETWORKS IN FIBER RINGS

Field of the Invention

The present invention relates to methods and devices for providing flexible and scalable architecture in networks. It is disclosed in the context of fiber optic communication networks, but is believed to be useful in other applications as well.

Disclosure of the Invention

According to an aspect of the invention, a node for a fiber optic communication network includes a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, a second device for demodulating from the first electrical signal first information modulated on the first optical signal, a third device for modulating on a second electrical signal second information, a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency, a fifth device for providing a third optical signal at a second frequency and a sixth device for multiplexing the second and third optical signals and placing the multiplexed second and third optical signals on the network. The third optical signal has third information modulated on it.

Illustratively according to this aspect of the invention, the network further carries a fourth optical signal at the second frequency. The apparatus further includes a seventh device for converting the fourth optical signal into a third electrical signal, and an eighth device for demodulating from the third electrical signal fourth information modulated on the fourth optical signal.

Further illustratively according to this aspect of the invention, the apparatus includes a ninth device for providing a fifth optical signal at a third frequency. The fifth optical signal has fifth information modulated on it. The sixth device multiplexes the second, third and fifth optical signals and places the multiplexed second, third and fifth optical signals on the network.

Additionally illustratively according to this aspect of the invention, the network further carries a sixth optical signal at the third frequency. The apparatus further includes a tenth device for converting the sixth optical signal into a fourth electrical signal, and an eleventh device for demodulating from the fourth electrical signal sixth information modulated on the sixth optical signal.

Illustratively according to this aspect of the invention, the apparatus further includes a seventh device for providing a fourth optical signal at a third frequency. The fourth optical signal has fourth information modulated on it. The sixth device multiplexes the second, third and fourth optical signals and places the multiplexed second, third and fourth optical signals on the network.

According to another aspect of the invention, a node for a fiber optic communication network includes a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, a second device for demodulating first information from the first electrical signal modulated on the first optical signal, a third device for modulating second information on a second electrical signal, and a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

Illustratively according to this aspect of the invention, the network further carries a third optical signal at a second frequency. The apparatus further includes a fifth device for converting the third optical signal into a third electrical signal having third information modulated on it.

Further illustratively according to the invention, the apparatus includes a sixth device for modulating fourth information on a fourth electrical signal, and a seventh device for converting the fourth information modulated on the fourth electrical signal into a fourth optical signal at the second frequency and placing the multiplexed second and fourth optical signals on the network.

Illustratively according to the invention, a fiber optic network includes a node of the first type described above and one or more nodes of the second type described above.

Illustratively according to the invention, the fiber optic network includes a closed loop optical fiber. One node of the first type described above and one or more nodes of the second type described above are coupled to the closed loop optical fiber.

Further illustratively according to the invention, the fiber optic network includes two closed loop optical fibers, each carrying a copy of the signals flowing in the network in opposite directions. Each node is coupled to both optical fibers to receive from the opposite directions two copies of the signals flowing in the network.

Brief Description of the Drawings

The invention may best be understood by referring to the following detailed descriptions of illustrative embodiments, and the accompanying drawings which illustrate the invention. In the drawings:

Fig. 1 illustrates a highly simplified block diagram of a network according to the present invention;

Fig. 2 illustrates a highly simplified block diagram of a component of a network according to the present invention;

Fig. 3 illustrates a highly simplified block diagram of a component of a network according to the present invention;

Fig. 4 illustrates a functional block diagram of a possible component of a network according to the present invention;

Fig. 5 illustrates a functional block diagram of a possible component of a network according to the present invention;

Figs. 6-8 illustrate the operation of certain possible components of a network according to the present invention;

Fig. 9 illustrates a functional block diagram of a possible component of a network according to the present invention;

Fig. 10 illustrates a functional block diagram of a component of a network according to the present invention;

Fig.11 illustrates a functional block diagram of a component of a network according to the present invention;

Fig. 12 illustrates a functional block diagram of a component of a network according to the present invention;

Fig. 13 illustrates a functional block diagram of a component of a network according to the present invention; and,

Fig. 14 illustrates a functional block diagram of a component of a network according to the present invention.

Detailed Descriptions of Illustrative Embodiments

In order to understand the invention, it is helpful to outline certain characteristics of a typical system which incorporates the invention. Referring to Fig. 1, a network 50 includes an arbitrary number of nodes 52 is interconnected in a ring by a pair of optical fibers 54. The data carriers in the optical fibers 54 are generated by an arbitrary number, N, of, for example, laser diodes, providing a respective arbitrary number of wavelengths λ1, λ2, . . . λN, λSRC in, for example, the 1550 nm and/or 1310 nm bands. These optical carrier sources provide the optical channels interconnecting the network 50 nodes 52, and these channels, or wavelengths λ1, λ2, . . . λN, λSRC, are carried in a single fiber 54 using Dense Wavelength Division Multiplexing (DWDM) technology. Each such wavelength λ1, λ2, . . . λN, λSRC is hereinafter sometimes referred to as an optical channel.

It is not essential to an implementation of the invention that a particular bit rate or range of bit rates be employed, and so the bit rate of each optical channel λ1, λ2, . . . λN, λSRC is arbitrary and independent of the rates of other channels λ1, λ2, . . . λN, λSRC. The protocol used by each optical channel λ1, λ2, . . . λN, λSRC is arbitrary and independent of the protocol(s) used by other channels λ1, λ2, . . . λN, λSRC. Examples of various protocols which may be implemented in various ones of the channels λ1, λ2, . . . λN, λSRC carried on systems constructed according to the invention include SONET/SDH, ATM and IP. In the illustrated embodiments, all channels λ1, λ2, . . . λN, λSRC are assumed to be using SONET/SDH framing. Channels λ1, λ2, . . . λN, λSRC which use different protocols, ATM and IP, for example, are simply mapped into the SONET/SDH frames using established standards

and techniques. Both the hub node 52-1 and the terminal nodes 52-2 have the capability to effect the appropriate protocol processing on both the upstream traffic and the downstream traffic.

The invention provides cost-effective architectures for DWDM-based access networks 50 implemented over optical fiber 54 rings. Such networks 50 can carry diverse types of traffic (for example, SONET, ATM, IP, and so on) and even mix different types of traffic in the same optical fiber 54 rings. One of the nodes 52 is designated the hub node 52-1. The other nodes 52 are referred to as terminal nodes 52-2. The traffic pattern in the network 50 is such that terminal nodes 52-2 communicate predominantly with the hub node 52-1, but sometimes with each other. Hub node 52-1-to-terminal node 52-2 traffic is sometimes referred to herein as downstream traffic. Terminal node 52-2-to-hub node 52-1 traffic is sometimes referred to herein as upstream traffic.

According to the invention, a specific optical channel λSRC is used as a Shared Ring Channel (SRC). λSRC is optically dropped and re-generated by each node 52. In the process of dropping and regenerating λSRC, the terminal nodes 52-2 can add in and drop their own traffic. The method used to multiplex the traffic of the different nodes 52 on λSRC depends on the protocol being used. The hub node 52-1 can drop and demultiplex the traffic it receives on λSRC into the separate streams generated by each terminal node 52-2, and likewise can multiplex and add the data streams intended for the different terminal nodes 52-2. The wavelength λSRC may be, for example, 1310nm, 1510nm, or any other optical wavelength defined by the ITU grid. A cost-effective implementation uses the 1310nm wavelength for λSRC. The components for the 1310nm wavelength are widely available and relatively inexpensive.

The network 50 control channel, used for management and fault reporting, is also carried by λSRC. Because λSRC is dropped and added at each node 52, it will be appreciated that control information may flow from any node 52 to any other node 52. For example, the hub node 52-1 can insert into the network 50 control information intended for any subset of the terminal nodes 52-2.

The method used to multiplex the control information and the different data channels on λSRC depends on the protocol(s) being used in the network 50. One approach, applicable when the data channels in the network 50 use SONET/SDH framing, is to have the control channel use the DCC bytes in the section overhead of the SONET/SDH signal. Another approach, applicable to the ATM protocol, is to assign a specific ATM VC to the control flow, and other VCs or VPs to the upstream channels.

In addition to λSRC, multiple optical channels λ1, λ2, . . . λN can be used to increase the bandwidth capacity from the hub node 52-1 to specific terminal nodes 52-2. Each terminal node 52-2 can be connected to one or more optical channels λK, λL, . . . λP, $1 \leq K, L, \ldots P \leq N, K \neq L \neq \ldots P$. The hub node 52-1 is connected to all optical channels λ1, λ2, . . . λN. An optical channel λ1, λ2, . . . λN can be shared among multiple terminal nodes 52-2. An optical channel λ1, λ2, . . . λN can be either symmetric, that is, it carries both hub node 52-1-to-terminal node 52-2 and terminal node 52-2-to-hub node 52-1 traffic, or asymmetric, that is, it carries only hub node 52-1-to-terminal node 52-2 traffic. The bit rate(s) fK, fL, . . . fP of the optical channel(s) λK, λL, . . . λP intended for a specific terminal node 52-2 can be matched to the bandwidth requirements of that terminal node 52-2, and is (are) independent of the bit rates used by other optical channels.

Protection against certain network 50 and equipment failures is provided by using two parallel fiber optic rings 56, 58 which carry their traffic in opposite directions. Where each signal is transmitted in both directions, the receiver can select the best received copy (similar to UPSR in SONET/SDH rings). The two directions are sometimes referred to herein as west-to-east (fiber 56) and east-to-west (fiber 58).

Thus, the following three types of terminals can all exist on the same fiber optic ring network 50: shared ring terminals, which transmit and receives all their traffic on λSRC; asymmetric terminals, which transmit all their traffic on λSRC and may receive traffic from both λSRC and one or more associated optical channels λK, λL, . . . λP; and, symmetric terminals, which can transmit and receive traffic both on λSRC and on one or more associated symmetric optical channels λK, λL, . . . λP. Shared ring terminals are typically less expensive than asymmetric terminals. Asymmetric terminals,

in turn, are typically less expensive than symmetric terminals. This commends the following strategy for a network 50 operator deploying rings based upon this architecture. Initially, when demand at all terminal nodes 52-2 is relatively low, shared ring terminals are deployed at each such site, and a hub system is provided at the hub node 52-1. When the bandwidth requirements of a specific terminal node 52-2 increase, one or more dedicated optical channels λK, λL, . . . λP can be established between this terminal node 52-2 and the hub node 52-1, with this terminal node 52-2's system upgraded to a symmetric or asymmetric terminal, depending upon whether the traffic pattern between the hub node 52-1 and this terminal node 52-2 is symmetric or asymmetric, respectively. This network 50 architecture combines relatively low entry cost with the ability to scale each terminal node 52-2's capacity upward when and where required. This architecture permits SRC terminals, asymmetric terminals and symmetric terminals all to reside on the same ring. The upgrading of a terminal node 52-2 from a shared ring terminal to an asymmetric or symmetric terminal can be accomplished while the node 52-2 is in service, that is, without interrupting the flow of traffic, and without requiring any change in any other terminal node.

Fig. 2 illustrates a high-level functional diagram of terminal nodes 52-2. A processing subsystem 60 provides protocol processing appropriate to a particular application. Examples include SONET/SDH multiplexers and ATM multiplexers. The processing subsystem 60 provides electrical signals to an optical subsystem 62, to be transmitted on λSRC and potentially on one or more associated dedicated optical channels λK, λL, . . . λP, and receives electrical signals derived from λSRC and potentially the associated dedicated optical channel(s) λK(, λL, . . . λP). The processing subsystem 60 typically also has external ports of different types in order to connect external devices which use the transport services of network 50. The optical subsystem 62 implements the optical add/drop function for λSRC and potentially the optical add/drop function for the optical channel(s) λK(, λL, . . . λP) in symmetric and asymmetric terminal types. It also incorporates the required receivers/transmitters. A control subsystem 64 manages, configures and monitors the operation of the processing

and optical subsystems 60, 62, respectively, and handles communications on the control channel.

Fig. 3 illustrates a high-level functional diagram of a hub node 52-1. A processing subsystem 66 provides protocol-related processing functions such as the cross-connect/switching function and protocol processing for wavelengths λ1, λ2, . . . λN, λSRC generated by hub node 52-1. In case of a SONET/SDH application, the processing subsystem 66 may provide the functionality of a SONET/SDH cross-connect, as well as all SONET/SDH-related protocol processing. In the case of an ATM application, the processing subsystem 66 may provide the functionality of an ATM VPX/switch and the associated protocol processing. In case of mixed traffic, both SONET cross-connect and ATM switching functionality can be provided simultaneously. The processing subsystem 66 provides to an optical subsystem 68 an electrical channel for each optical channel λ1, λ2, . . . λN generated by this node 52-1 as well as for λSRC. The processing subsystem 66 receives the electrical signals derived from λSRC and from incoming optical signal λ1, λ2, . . . λN. The processing subsystem 66 typically also has external ports of different types in order to connect external devices which use the transport services of the network 50. The optical subsystem 68 has the capability to generate/terminate all the optical channels λ1, λ2, . . . λN being used in the network 50. The optical subsystem 68 incorporates multiplexing/demultiplexing functionality for the optical channels λ1, λ2, . . . λN, as well as suitable transmitters and receivers. The optical subsystem 68 also provides an optical interface to λSRC. A control subsystem 70 manages, configures and monitors the operation of the processing and optical subsystems 66, 68, respectively, and handles all communications on the control channel.

As previously noted, a network 50 constructed according to the invention typically includes a pair of parallel optical fibers 54 which carry signals in opposite directions. For each of the three terminal node 52-2 types, shared ring, symmetric and asymmetric, the optical subsystem 62 includes two similar or identical blocks, one operating on the west-to-east fiber 56 and the other on the east-to-west fiber 58. The purpose of having the two identical blocks is to achieve protection and redundancy.

Fig. 4 illustrates a structure for one of the optical subsystem blocks 71 (either west-to-east, 56, or east-to-west, 58) of a shared ring terminal 72. The incoming fiber 54 (Fiber IN) carries an optical signal including one or more wavelengths λ1, λ2, . . . λN, λSRC. Several optical channels λ1, λ2, . . . λN can be present in the signal, and those channels pass through optical subsystem block 71 unchanged. The combined optical signal λ1, λ2, . . . λN, λSRC is coupled through an optical drop component 74 for λSRC. The optical drop component 74 removes λSRC from the combined incoming signal λ1, λ2, . . . λN, λSRC and provides λSRC to an SRC receiver 76. The remaining wavelengths λ1, λ2, . . . λN pass unchanged through the optical drop component 74 to an SRC optical add function 80.

The exact nature of the SRC optical drop component 74 depends on the wavelength used for that channel. Suitable components 74 are commercially available for, for example, 1310nm, 1510nm, or any other optical wavelength defined by the ITU grid. For example, for a 1310nm carrier, an inexpensive coupler may be used to achieve the required functionality.

The SRC receiver 76 converts λSRC into an electrical signal. Such receivers 76 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 82, which decomposes the incoming stream into three components, a control component 84, a dropped data component 86 (data intended for the local terminal 52-2), and a through data component 88 (data intended for other nodes 52). The exact nature of the SRC drop function 82 depends on the structure of the signal. In case of a SONET/SDH signal, the control components typically can be stored in the DCC bytes of the section overhead in the SONET/SDH frames. The different data components will reside in different SONET/SDH sub-channels. The decomposition of the incoming stream into control component 84, dropped data component 86, and through data component 88 can be done by commercially available SONET/SDH framing components such as, for example, the SPECTRA devices available from PMC-Sierra. In the case of an ATM or IP signal, the control sub-channel will be carried as a specific VC in an ATM cell flow or a packet flow with a distinct header in an IP packet stream. Likewise the flows belonging to the different data

components will be carried by specific VCs or by IP packets with distinct headers. Suitable hardware is available to effect the required separation. This type of functionality is normally found in any ATM switching system or IP routing system, respectively.

The resulting isolated control component 84 is coupled to the control subsystem 64 (Fig. 2). The resulting isolated dropped data component is coupled to the processing subsystem 60. The through component 88 is coupled to an SRC add function 92. The SRC add function 92 multiplexes the data stream provided by the processing subsystem 60, as well as the control channel originating in the control subsystem 64, with the through channel 88 from the SRC drop function. Again, the exact nature of this multiplexing function depends on the type and format of the signal, as explained for the drop function 82. The SRC add function 92 can be implemented with the same types of components and logical hardware mentioned above. The resulting signal is converted by an SRC transmitter 94 into an optical signal. The type of transmitter 94 required depends on the wavelength λSRC. Transmitters 94 are commercially available for, for example, 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid.

The optical signal generated by the SRC transmitter 94 is incorporated into the combined optical signal λ1, λ2, . . . λN by the optical add function 80 for λSRC. The resulting Fiber OUT signal contains all pass-through wavelengths λ1, λ2, . . . λN, as well as λSRC, carrying the locally (re)generated signal.

Fig. 5illustrates a structure for one of the optical subsystem blocks 100 (either on the west-to-east fiber 56 or on the east-to-west fiber 58) for an asymmetric terminal 102. The incoming fiber 54 (Fiber IN) carries an optical signal including multiple wavelengths λ1, λ2, . . . λN, λSRC, one or more of which is (are) the specific downstream channel(s) λK(, λL, . . . λP) associated with asymmetric terminal 102. Several other wavelengths (λ1, λ2, . . . λN)-λK(, λL, . . . λP) may be present in the signal, and they pass through optical subsystem block 100 unaffected. The combined optical signal λ1, λ2, . . . λN, λSRC is coupled to an optical drop component 104 for the wavelength λSRC. Optical drop component 104 may be of the same configuration as optical drop component 74 described above in connection with the description of the shared ring terminal 72.

An SRC receiver 106 converts λSRC into an electrical signal. Such receivers 106 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 108, which decomposes the incoming stream into a control component 110, a dropped data component 112 (data intended for the local terminal) and a through data component 114 (data intended for other nodes 52). The SRC drop function 108 can be implemented similarly to the SRC drop function 82 described above in connection with the description of the shared ring terminal 72. The resulting isolated control flow 110 is coupled to the control subsystem 64. The resulting isolated dropped data component 112 is coupled to the processing subsystem 60. The through component 114 is coupled to an SRC add function 118.

After passing through the optical drop 104 for λSRC, the incoming optical signal λ1, λ2, . . . λN is coupled to an optical drop 120 for the optical channel(s) λK(, λL, . . . λP) assigned to this asymmetric terminal. The optical drop 120 couples the optical channel(s) λK(, λL, . . . λP) associated with this node 52-2 from the combined incoming signal λ1, λ2, . . . λN to a receiver 122. The remaining wavelengths (λ1, λ2, . . . λN)-λK(, λL, . . . λP) pass through the receiver 122 unaffected. The optical drop function 120 may either completely remove the optical channel(s) λK(, λL, . . . λP) assigned to this asymmetric terminal 102 from the fiber 56 or 58 (so-called "drop only" functionality) or it may drop (a) "copy(ies)" of the optical channel(s) λK(, λL, . . . λP) assigned to this asymmetric terminal 102 and also permit the wavelength(s) λK(, λL, . . . λP) to continue (so-called "drop and continue" functionality). These two options are illustrated in Figs. 6 and 7, respectively. Of course, although it is not illustrated in the drawings, if any terminal employs drop and continue functionality, λK(, λL, . . . λP), the "dropped" frequency (ies) will appear in outputs from the optical drop component(s), that is, it (they) will be both "dropped" and "continued."

Drop only functionality (Fig. 6) can be achieved by using optical drop components 120 available from several vendors. It is also possible to use only the drop function of an optical add/drop multiplexer, or OADM. Drop and continue functionality (Fig. 7) can be achieved more cost-effectively by a coupler on the signal path from an optical drop component 104 which splits the signal's energy and couples a portion of that

energy into another fiber 124. This fiber 124 is coupled to an optical band-pass filter 126 that permits only the specified wavelength to pass. This is illustrated in Fig. 8. The described components are commercially available from several vendors.

Receiver(s) 122K(, 122L, . . . 122P) convert(s) the optical signal(s) λK(, λL, . . . λP) into (an) electrical signal(s). Such receivers 122 are commercially available from several vendors. The resulting electrical signal(s) is (are) coupled to the processing subsystem 60.

SRC add function 118 multiplexes a data stream coupled from the processing subsystem 60, a control channel 110 coupled from the control subsystem 64 and a through channel 114 coupled from the SRC drop function 108. The SRC add function 118 may be implemented in the same way as SRC add function 92 described in connection with the description of the shared ring terminal 72. The resulting signal is converted by an SRC transmitter 134 into an optical signal λSRC. The type of SRC transmitter 134 depends on the wavelength λSRC. Transmitters 134 are commercially available for, for example, 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid.

The optical signal λSRC generated by the SRC transmitter 134 is incorporated into the combined optical signal λ1, λ2, . . . λN, λSRC by an optical add function 136 for the SRC. The resulting Fiber OUT signal λ1, λ2, . . . λN, λSRC contains all pass-through wavelengths, including λSRC, carrying the locally (re)generated signal.

Fig. 9 illustrates a structure for one of the optical subsystem blocks 140 (either on west-to-east fiber 56 or on east-to-west fiber 58) for a symmetric terminal 142 according to the invention. The incoming fiber 54 (Fiber IN) carries an optical signal including various wavelengths λ1, λ2, . . . λN, λSRC one (or ones) of which is(are) the specific optical channel(s) λK(, λL, . . . λP) associated with terminal 142. Several other wavelengths (λ1, λ2, . . . λN)-λK(, λL, . . . λP) may be present in the signal, and they will pass through optical subsystem block 140 unchanged.

The combined optical signal λ1, λ2, . . . λN, λSRC is coupled to an optical drop component 144 for λSRC. Optical drop component 144 may be of the same

configuration as optical drop component 74 described above in connection with the description of the shared ring terminal 72.

An SRC receiver 146 converts λSRC into an electrical signal. Such receivers 146 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 148, which decomposes the incoming stream into a control component 150, a dropped data component 152 (data intended for the local terminal 52-2) and a through data component 154 (data intended for other nodes 52). The SRC drop function 148 can be implemented similarly to the SRC drop function 82 described above in connection with the description of the shared ring terminal 72. The resulting isolated control flow 150 is delivered to the control subsystem 64. The resulting isolated dropped data component 152 is coupled to the processing subsystem 60. The through component 154 is coupled to an SRC add function 158.

After the SRC drop function 148, the incoming signal (without λSRC) is coupled to an optical drop 158 for the optical channel(s) λK(, λL, . . . λP). Optical drop 158 isolates the optical channel(s) λK(, λL, . . . λP) associated with this node 52-2 from the combined incoming signal and provides λK(, λL, . . . λP) to (a) receiver(s) 160K(, 160L, . . . 160P). The remaining wavelengths (λ1, λ2, . . . λN)-λK(, λL, . . . λP) pass through optical drop 158 unchanged. The optical drop function 158 removes the wavelength(s) λK(, λL, . . . λP) from the fiber 56 or 58. The exact nature of the optical drop component 158 for the optical channel depends on the wavelength(s) λK(, λL, . . . λP) associated with this node 52-2. Suitable components 158 are commercially available for any optical wavelength defined by the ITU grid. The receiver(s) 160K(, 160L, . . . 160P) transform(s) the isolated optical channel(s) λK(, λL, . . . λP) into (an) electrical signal(s). Such receivers 160 are commercially available from several vendors. The resulting electrical signal(s) is(are) coupled to the processing subsystem 60.

(A) transmitter(s) 162K(, 162L, . . . 162P) transform(s) the electrical signal(s) coupled from the processing subsystem 60 into (an) optical signal(s) at the wavelength(s) λK(, λL, . . . λP) appropriate for this (these) optical channel(s) λK(, λL, . . . λP). Such transmitters 162 are commercially available from several vendors. The resulting optical signal(s) is (are) then incorporated into the combined optical signal by

(an) optical add component(s) 164K(, 164L, . . . 164P) suitable for wavelength(s) λK(, λL, . . . λP). Suitable components 164 are commercially available for any optical wavelength(s) λK(, λL, . . . λP) defined by the ITU grid. The output signal(s) of this (these) component(s) 164K(, 164L, . . . 164P) contains λ1, λ2, . . . λN. The optical channel optical drop 158 and optical add 164 functions may be integrated into (an) OADM(s).

SRC add function 158 multiplexes the data stream 152 coupled from the processing subsystem 60, the control channel 150 coupled from the control subsystem 64, and the through channel 154 coupled from the SRC drop function 148. The SRC add function 158 may be implemented in the same way as SRC add function 92 described in connection with the description of the shared ring terminal 72. The resulting signal is converted by an SRC transmitter 168 into an optical signal. The type of transmitter 168 required depends on the wavelength used for the SRC. Transmitters are commercially available for, for example, 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid. The optical signal λSRC generated by the SRC transmitter 168 is incorporated into the combined optical signal λ1, λ2, . . . λN by an optical add function 170 for the SRC. The resulting Fiber OUT signal contains all pass-through wavelengths (λ1, λ2, . . . λN)-λK(, λL, . . . λP), plus the locally generated optical channel(s) λK(, λL, . . . λP), plus the wavelength λSRC used for the SRC, carrying the locally (re)generated signal.

As noted above, in all three terminal types 72, 102, 142 a similar optical block 71, 100, 140 is provided on the other fiber 54. In this way, the processing subsystem 60 gets input from both fiber 56 and fiber 58 through their respective optical blocks. In the case of dedicated DWDM channels, the content of these two data streams should be identical unless there is some fault in the network 50 that results in disruption of the signal flow. The processing subsystem 60 must therefore select at any time which input to process and which to discard. The selection is based on the relative quality of the received signals, measured by the performance monitoring provisions of the protocols used in a particular application. The data channel generated by the processing subsystem

60 must be duplicated and transmitted to both optical blocks. This applies to the data traffic on the dedicated optical channel, if used.

The mechanism used for the SRC is somewhat different. Unlike the dedicated optical channels λ1,λ2, . . . λN, which can be seen as logical point-to-point links to the hub 52-1, any node 52 can receive traffic on the SRC from any other node 52 on the ring. In case of a fault anywhere in the network 50, each channel of such traffic will be received either from the east, on fiber 58, or from the west, on fiber 56. It follows that the processing subsystem 60 of a particular node 52-2's terminal must have a selection function for the SRC, that exhibits the following behavior. When no fault that results in disruption of the SRC is present in the network 50, either the east copy (on fiber 58) or the west copy (on fiber 56) of the SRC must be selected. Selection is based on the relative quality of the received signals, measured by the performance monitoring provisions of the protocols used in a particular application. When a fault that results in disruption of the SRC exists, the channels arriving from the east should be combined with those arriving from the west in such a way that one valid copy of each channel is available. This mechanism is similar to that used in SONET path protection, for example, in SONET UPSR rings. The same holds true for the interaction between the control subsystem 64 and the optical subsystem 62 with respect to the control channel. This is illustrated in Fig. 10.

Fig. 11 illustrates a structure for the optical subsystem block 180 that operates on the west-to-east fiber 56 in a hub node 52-1. To achieve protection and redundancy, a similar block operates on the east-to-west fiber 58. The interaction between the two blocks 180 is discussed below. In this example, some terminal nodes 52-2 operate in shared ring mode, meaning the hub 52-1 transmits and receives their traffic exclusively on λSRC. Three terminal nodes 52-2 (those associated with λ1 , λ2 and λN) operate in symmetric mode, while the terminal associated with λ3 operates in asymmetric mode, as evidenced by the fact that there is no receiver for an upstream optical channel for the wavelength λ3.

The incoming fiber (Fiber IN) carries an optical signal including λSRC and potentially optical wavelengths λ1 , λ2, . . . λN used for upstream channels. The

combined signal first goes through an optical drop component 182 for the wavelength λSRC. Component 182 may be of the same type as optical drop component 74 described above in connection with shared ring terminal 72.

An SRC receiver 186 converts λSRC into an electrical signal. Such receivers 186 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 188, which decomposes the incoming stream into a control component 190, a set 192 of upstream channels from all terminal nodes 52-2 (it is assumed that the processing subsystem 66 can break this multiplexed stream into its constituent channels), and a through data component 194 (data intended for other nodes 52-2). The SRC drop function 188 can be implemented in the same manner as the SRC drop function 82 described above in connection with the description of the shared ring terminal 72. The resulting isolated control flow 190 is delivered to the control subsystem 70. The resulting isolated upstream channels 192 are coupled to the processing subsystem 66. The through component 194 is coupled to an SRC add function 198.

After the optical drop for SRC function, the incoming optical signal without λSRC is coupled to a DWDM demultiplexer 200. DWDM demultiplexer 200 demultiplexes the DWDM signal into its constituent wavelengths λ1, λ2, . . . λN. Each wavelength is then either coupled to a suitable receiver 202-1, 202-2, 202-4, . . . 202-N for λ1, λ2, λ4, . . . λN, respectively, or discarded, as in the case of λ3, recalling that the terminal node 52-2 associated with λ3 operates in asymmetric mode. Such DWDM demultiplexers 200 are commercially available from several vendors. The receivers 202-1, 202-2, 202-4, . . . 202-N transform their respective isolated DWDM channels λ1, λ2, λ4, . . . λN into electrical signals. Such receivers 202-1, 202-2, 202-4, . . . 202-N are commercially available from several vendors. The resulting electrical signals are coupled to the processing subsystem 66.

The electrical downstream channels provided by the processing subsystem 66 are transformed by their respective DWDM transmitters 204-1, 204-2, . . . 204-N into optical signals. The DWDM transmitters 204-1, 204-2, . . . 204-N are components suitable for the wavelengths λ1, λ2, . . . λN used for their respective downstream

channels. Such transmitters 204-1, 204-2, . . . 204-N are commercially available from several vendors. The optical signals λ1 , λ2, . . . λN output by these transmitters are then combined for insertion into west-to-east fiber 56 by a DWDM multiplexer component 206. DWDM multiplexer components 206 are commercially available from several vendors. The output signal of this component contains all the DWDM wavelengths λ1 , λ2, . . . λN generated by the local transmitters 204-1, 204-2, . . . 204-N. This signal is coupled to an optical add function for SRC 208.

SRC add function 198 combines the multiplexed data stream provided by the processing subsystem 66, the control channel originating in the control subsystem 70, and the through channel from the SRC drop function 188. The resulting signal is converted by an SRC transmitter 210 into an optical signal. The type of transmitter 210 required depends on the wavelength used for the SRC. Transmitters 210 are commercially available for 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid. Transmitter 210 is also coupled to SRC optical add function 208 to combine the optical SRC signal with the optical wavelengths generated by the local transmitters 204-1, 204-2, . . . 204-N. SRC optical add function 208 may be implemented in the same manner as SRC add function 166 described in connection with the description of symmetric terminal 142. The resulting Fiber OUT signal contains all wavelengths λ1 , λ2, . . . λN used for the downstream channels as well as the wavelength λSRC used for the SRC.

As previously noted, an optical block 180 similar to the one just described is provided for the east-to-west fiber 58. The protection mechanisms described above for the terminal nodes 52-2, with respect to the dedicated optical channels and the data and control flows on the SRC, also apply to the east-to-west fiber 58. In particular, an independent selection and duplication function is applied to each optical channel in use.

Another embodiment of the invention is a special case of the embodiment described above, in which only shared ring and asymmetric terminals are employed. This embodiment includes an implementation of the hub node optimized for this case. This embodiment is useful for providing unidirectional optical channels. The traffic pattern is, of course, asymmetric in the sense that the volume of downstream traffic is

much higher than the volume of upstream traffic. An example of this type of environment include xDSL traffic in which networks collect traffic from several sites containing DSL concentrators for routing to a regional hub node. ADSL traffic is inherently asymmetric, with downstream bandwidth up to an order of magnitude higher than the upstream bandwidth. Another example of this type of environment is cable modem traffic. Cable networks collect traffic from several sites containing cable modem headends for routing to a regional data hub node. Cable modem traffic is also inherently asymmetric. The required downstream bandwidth for a specific terminal node 52-2 is arbitrary and independent of the bandwidth required for any other terminal node 52-2. The aggregate bandwidth in the network 50 exceeds that which can be handled by any approach that makes use of a single optical channel such as, for example, a prior art SONET/SDH ring, thus commending the use of DWDM.

The hub node 52-1 includes a DWDM transmitter for each DWDM channel in use in the network 50. The hub node 52-1 also includes a multiplexer for combining all of the generated channels into a single fiber. Each terminal node 52-2 has the ability to drop one or more of the downstream channels and terminate the optical signal(s) with (a) suitable receiver(s). The received data stream(s) is (are) then processed. The rate(s) of the downstream channel(s) intended for a specific terminal can be matched to the bandwidth requirements of that terminal. In addition, several terminals may share the same downstream channel(s). This permits better utilization of the downstream channels. A significant advantage of this approach is that it reduces the number and cost of DWDM components. The hub node 52-1 needs one transmitter per channel in the network 50, and a suitable multiplexer. It does not require receivers or a demultiplexer. Each terminal node 52-2 requires a receiver for (each of) its downstream channel(s) and suitable components to drop its channel's (s') wavelength(s) from the network 50, but does not require a transmitter. Thus, this embodiment does not require that each node drop the downstream channels or add them. The optical drop function at the terminal nodes 52-2 is thereby made less expensive, and the optical add function at the terminal nodes 52-2 is eliminated entirely. Each terminal node 52-2 still must be able to drop and add the λSRC, which requires a suitable receiver and transmitter. As

noted above, if the 1310 nm wavelength is used for λSRC, the required components are relatively inexpensive.

A specific optical channel λSRC is used as the SRC to collect upstream traffic from all nodes. λSRC is optically dropped and re-generated by each node 52. In the process of dropping and regenerating λSRC, the terminal nodes 52-2 can add their own upstream traffic. The method used to multiplex the traffic of the different nodes 52-2 on λSRC depends on the protocol being used. The hub node 52-1 can drop and demultiplex the traffic it receives on λSRC into the separate streams generated by each terminal node 52-2. The wavelength λSRC may be, for example, 1310 nm, 1510 nm, or any other optical wavelength defined by the ITU grid. Again, a cost-effective implementation uses the 1310 nm wavelength for λSRC for the reasons previously noted.

The network 50 control channel, used for management and fault reporting, is also carried by λSRC. Because λSRC is dropped and added at each node 52, it will be appreciated that control information may flow from any node 52 to any other node 52. For example, the hub node 52-1 can insert into the network 50 control information intended for any subset of the terminal nodes 52-2.

The method used to multiplex the control information and the different data channels on λSRC depends on the protocol(s) being used in the network 50. As previously noted, and only by way of example, an approach applicable when the data channels in the network 50 use SONET/SDH framing is to have the control channel use the DCC bytes in the section overhead of the SONET/SDH signal. Each specific upstream channel would then use a different SONET/SDH sub-channel. Another approach, applicable to the ATM protocol, is to assign a specific ATM VC to the control flow, and other VCs or VPs to the upstream channels.

Referring now particularly to Fig. 12, the downstream traffic uses unidirectional optical channels λ1, λ2, . . . λN. Specifically, the hub node has a DWDM transmitter 404-1, 404-2, . . . 404-N for each DWDM channel λ1, λ2, . . . λN in use, and a DWDM multiplexer 406 to combine all the generated channels λ1, λ2, . . . λN into a single fiber 54. Each terminal node 52-2 (Fig. 13) has the ability to drop one or more λK(, λL, . . . λP) of the downstream channels λ1, λ2, . . . λN and terminate the optical

signal(s) with (a) suitable receiver(s) 322. The resulting data stream(s) is (are) then processed. The rate(s) fK(, fL, . . . fP) of the downstream channel(s) λK(, λL, . . . λP) intended for a specific terminal 52-2 can be matched to the bandwidth requirements of that terminal 52-2. In addition, several terminals 52-2 may share the same downstream channel(s) λK(, λL, . . . λP). This permits greater utilization of the downstream channels λ1, λ2, . . . λN.

As in the first embodiment, protection against certain network 50 and equipment failures is provided by using two parallel fiber optic rings 56, 58 which carry their traffic in opposite directions. Where each signal is transmitted in both directions, the receiver can select the best received copy (similar to UPSR in SONET/SDH rings).

The high level functional descriptions of the terminal nodes 52-2 and hub node 52-1 are the same as illustrated in Figs. 1 and 2, respectively.

Fig. 13 illustrates structure within the optical subsystem of a terminal node 52-2 that operates on the west-to-east fiber 56. To achieve protection and redundancy, another similar or identical structure operates on the east-to-west fiber 58. The incoming fiber (Fiber IN) carries an optical signal including λSRC and the wavelengths λ1, λ2, . . . λN, one or more, λK(, λL, . . . λP), of which is (are) the specific downstream channel(s) associated with this terminal 52-2. Several other wavelengths (λ1, λ2, . . . λN)-λK(, λL, . . . λP) may be present, and these will pass through the structure illustrated in Fig. 13 and its complement on the east-to-west fiber 58 unchanged. The combined optical signal λ1, λ2, . . . λN, λSRC is coupled to an optical drop component 304 for λSRC. Component 304 removes the wavelength λSRC associated with the SRC from the combined incoming signal (λ1, λ2, . . . λN, λSRC) and provides the isolated SRC wavelength λSRC to an SRC receiver 306. The remaining wavelengths λ1, λ2, . . . λN pass through component 304 unchanged. Again, the exact nature of the SRC optical drop component 304 depends on the wavelength λSRC used for that channel. Suitable components 304 are commercially available for, for example, 1310nm, 1510nm, or any other optical wavelength defined by the ITU grid.

SRC receiver 306 converts λSRC into an electrical signal. Such receivers 306 are commercially available from several vendors. The resulting electrical signal is

coupled to an SRC drop function 308, which separates the control component in the SRC from the data component. The exact nature of the drop function 308 depends on the structure of the signal. In case of a SONET/SDH framed signal, for example, the SRC drop function 308 must isolate the information contained in the DCC bytes of the section overhead in the SONET/SDH frames. This can be done by commercially available SONET/SDH framing components such as the SPECTRA or SUNI devices from PMC-Sierra. If the control sub-channel is carried as a specific VC in an ATM cell flow or a specifically addressed packet flow in an IP packet stream, suitable hardware can be devised to effect the required separation functionality. This type of functionality is normally found in any ATM switching system or IP routing system, respectively. The resulting isolated control flow is delivered to the control subsystem 64 (Fig. 2). The resulting isolated data stream, containing the through traffic, such as, for example, downstream channels of terminals 52-2 other than the illustrated terminal 52-2, is forwarded as is to an SRC add function 318, described below.

After passing through the optical drop 304 for λSRC, the incoming optical signal λ1, λ2, . . . λN is next coupled to (an) optical drop(s) 320 for the optical channel(s) λK(, λL, . . . λP) assigned to the illustrated terminal 52-2. The optical drop(s) 320 couple(s) the optical channel(s) λK(, λL, . . . λP) associated with this node 52-2 from the combined incoming signal λ1, λ2, . . . λN to receiver(s) 322. The remaining wavelengths (λ1, λ2, . . . λN)-λK(, λL, . . . λP) pass through the optical drop function 320 unaffected. The optical drop function 320 may be achieved in different ways, and some options are illustrated in Figs. 5-7.

Receiver(s) 322 convert(s) the optical signal λK(, λL, . . . λP) into (an) electrical signal(s). Such receivers 322 are commercially available from several vendors. The resulting electrical signal is coupled to the processing subsystem 60.

SRC add function 318 multiplexes a data stream coupled from the processing subsystem 60, a control channel 310 coupled from the control subsystem 64 and a through channel 314 coupled from the SRC drop function 308. The SRC add function 318 may be implemented in the same way as SRC add function 92 described in connection with the description of the shared ring terminal 72. The resulting signal is

converted by an SRC transmitter 334 into an optical signal λSRC. The type of SRC transmitter 334 depends on the wavelength λSRC. Transmitters 334 are commercially available for, for example, 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid.

The optical signal λSRC generated by the SRC transmitter 334 is incorporated into the combined optical signal (λ1, λ2, . . . λN) by an optical add function 336 for the SRC. The resulting Fiber OUT signal (λ1, λ2, . . . λN) contains all pass-through wavelengths, including λSRC, carrying the locally (re)generated signal.

As noted above, a similar optical block is provided on the east-to-west fiber 58. In this way, the processing subsystem 60 gets input from both fiber 56 and fiber 58 through their respective optical blocks. In the case of the downstream DWDM channels, the content of these two data streams should be identical unless there is some fault in the network 50 that results in disruption of the signal flow. The processing subsystem 60 must therefore select at any time which input to process and which to discard. The selection is based on the relative quality of the received signals, measured by the performance monitoring provisions of the protocols used in a particular application. As before, any node 52 can receive traffic on the SRC from any other node 52 on the ring. In case of a fault anywhere in the network 50, each channel of such traffic will be received either from the east, on fiber 58, or from the west, on fiber 56. It follows that the processing subsystem 60 of a particular node 52-2's terminal must have a selection function for the SRC, that exhibits the following behavior. When no fault that results in disruption of the SRC is present in the network 50, either the east copy (on fiber 58) or the west copy (on fiber 56) of the SRC must be selected. Selection is based on the relative quality of the received signals, measured by the performance monitoring provisions of the protocols used in a particular application. When a fault that results in disruption of the SRC exists, the channels arriving from the east should be combined with those arriving from the west in such a way that one valid copy of each channel is available. Again, this mechanism is similar to that used in SONET path protection, for example, in SONET UPSR rings. The same holds true for the interaction between the

control subsystem 64 and the optical subsystem 62 with respect to the control channel. This is illustrated in Fig. 14.

Fig. 12 illustrates a structure for the optical subsystem block 380 that operates on the west-to-east fiber 56 in a hub node 52-1 according to the invention. To achieve protection and redundancy, a similar block 380 operates on the east-to-west fiber 58. The interaction between the two blocks 380 is discussed below.

The incoming fiber (Fiber IN) carries an optical signal including the SRC wavelength λSRC and potentially optical wavelengths λ1 , λ2, . . . λN used for downstream channels. The downstream channel wavelengths were originally transmitted by the hub node 52-1 and presumably have been dropped and continued by terminal nodes 52-2 along the network 50. In any case, they have no further use once they reach the hub node 52-1, and are discarded. The combined signal is coupled to an optical drop component 382 for λSRC. Component 382 may be of the same type as optical drop component 74 described above in connection with shared ring terminal 72.

An SRC receiver 386 converts λSRC into an electrical signal. Such receivers 386 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 388, which decomposes the incoming stream into a control channel 390 and a set 392 of upstream channels from all terminal nodes 52-2. Again, the recovered signals in the channels 392 are of no further use and are discarded. The SRC drop function 388 can be implemented in the same manner as the SRC drop function 82 described above in connection with the description of the shared ring terminal 72. The resulting isolated control flow 390 is delivered to the control subsystem 70 (Fig. 3).

The electrical downstream channels provided by the processing subsystem 66 are transformed by their respective transmitters 404-1, 404-2, . . . 404-N into optical signals. The DWDM transmitters 404-1, 404-2, . . . 404-N are components suitable for the wavelengths λ1 , λ2, . . . λN used for their respective downstream channels. Such transmitters 404-1, 404-2, . . . 404-N are commercially available from several vendors. The optical signals λ1 , λ2, . . . λN output by these transmitters are then combined for insertion into west-to-east fiber 56 by DWDM multiplexer component 406. DWDM

multiplexer components 406 are commercially available from several vendors. The output signal of this component contains all the DWDM wavelengths λ1 , λ2, . . . λN generated by the local transmitters 404-1, 404-2, . . . 404-N. An SRC add function 408 prepares the data stream provided by the control channel 190 for conversion into an optical signal by an SRC transmitter 410. The type of transmitter 410 required depends on the wavelength used for the SRC. Transmitters 410 are commercially available for 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid. Transmitter 410 is coupled to an SRC optical add function 418 to combine the optical SRC signal with the DWDM wavelengths generated by the local transmitters 404-1, 404-2, . . . 404-N. SRC optical add function 408 may be implemented in the same manner as SRC add function 166 described in connection with the description of symmetric terminal 142.

The resulting Fiber OUT signal contains all wavelengths λ1 , λ2, . . . λN used for the downstream channels, as well as λSRC.

As previously noted, an optical block 380 similar to the one just described is provided for the east-to-west fiber 58. As the hub 52-1 does not receive any DWDM channels, it does not need to effect any selection function of DWDM channels for the purposes of protection. It does need, however, to transmit its downstream channels in both directions, in order to provide protection for the terminals 52-2. This is achieved by duplicating the downstream data channels generated by the processing subsystem 66 to both optical blocks 380. As in the case of the terminal node 52-2, a different mechanism is used for protecting the SRC. The required mechanism is identical to that described for the terminal node 52-2.